high-quality aquatic cover and provide food and substrate for aquatic insects on which fish feed. Sediment lost at the eroding bank is transported downstream and redeposited on point bars. This process initiates the habitat colonization and bank renewal process. When pronounced bends are formed, an unimpeded river will eventually cut off the bend by eroding a "shortcut" across the inside bend during high flows. Through this process, backwater swales and oxbow lakes are formed, providing important juvenile fish rearing areas and sources of foodweb production.

Rivers with armored banks (rock riprap) or naturally stable stream channels are more likely to have urban or agricultural land use encroachment into the riparian floodplain and forest. This encroachment often leaves room for only a narrow band of trees or shrubs along the bank and results in low habitat quality for fish and wildlife. Alluvial rivers with artificially hardened banks and static channels suffer a general loss of diversity and quality at the interface of aquatic and terrestrial habitats. Unfortunately, making rivers more predictable has led to a decline in river ecosystem quality because the species and habitats that evolved on rivers are dependent on the changing, natural disturbance cycles of meandering streams.

All Central Valley streams have been affected by stressors that diminish stream meandering and associated aquatic and riparian habitats. However, significant reaches of several large rivers still support full or partial characteristics of a dynamic stream meander pattern. The best example in California is the Sacramento River between Red Bluff and Butte City. Other important examples include the San Joaquin River (from Mossdale to Merced River); the Merced, Tuolumne, Cosumnes, Feather, and Yuba rivers; and Cottonwood, Stony, and Cache creeks.

Natural meander belts tend to be the least impaired where there are no major levees or where levees are set back several hundred feet from the main channel bank; on rivers that have high flow stage during frequent flood peaks, thereby discouraging land conversion to urban or agricultural uses; and on rivers with floodplain soils that are not conducive to high-yield crops or orchards (e.g., saline hardpan soils along the lower San Joaquin River or gravelly, barren floodplains along the Yuba River).

To support a natural, dynamic stream meander system, the following important characteristics are needed, and identified stressors must be overcome or compensated for:

- A supply of gravel and sediment that matches the net transport and displacement of channel sediment and bedload. Dams interfere with the natural sediment supply from upstream, while levees, instream gravel mining, and bank protection projects deplete channel and floodplain sediment supplies. Most of the major tributaries of the Sacramento and San Joaquin rivers have large dams above an elevation of 300 feet. Most of the length of these rivers in the valley floor are being mined or have been mined for gravel, and all are confined by leveed and incised channels along substantial portions upstream of the Delta.
- A series of periodic flood peaks of sufficient magnitude and duration to remobilize and rearrange gravel and cobble deposits, transport sand and fine sediment to form new or expanded point bars, and erode banks or low bars on outside bends. Dam releases typically tame flows or eliminate flood peaks in dry or normal years. Tamed flows reduce bedload transport capacity while increasing base flows during summer. Channelization and levee confinement cause high flows to become deeper to compensate for less floodplain width, resulting in artificially increased sediment transport capacity. This reduced capacity prevents sediment capture in the off-channel floodplains and removes sediment from shallow shoal and bar deposits. The absence of frequent high-energy flows also prevents the scour of riparian vegetation, reducing the rate of natural sediment and cottonwood regeneration.
- Dense vegetation occupying the channelbanks and adjacent low floodplains to stabilize the river planform (i.e., modulate the annual rate of bank migration), reduce river flow velocities to cause new sediment to aggrade on bars, build topsoil in higher floodplains, and provide shade and instream woody cover to the aquatic zone. Narrow channels created by levees set too close to the low-flow shoreline separate the river from its floodplain and leave little room for riparian vegetation. Bank protection eliminates or

reduces vegetation on outside bends. Channel hardening discourages both erosion and point bar formation, resulting in a static, similarly-aged stand of riparian forest and a narrowing or discontinuity of the riparian cover. Artificially narrowed channels may require periodic vegetation removal to maintain minimum floodflow capacity and are more likely to require expensive bank riprap to protect the vulnerable levees during high flows.

- Adequate floodplain width to absorb and pass out-of-bank flows (i.e., the natural flood stage), capture fine sediments, store and filter woody debris, and, most importantly, make room for the progressive meander migration of the river channel within its floodplain. Loss of river floodplain functions has converted dynamic riverine ecosystems to static conveyance facilities for the transport of irrigation and drinking water and floodflow management. Urban encroachment in floodplains and meander belts usually follows river confinement and bank hardening.

- Development of innovative means to meet local or riparian water supplies without the need to install bank protection for diversion points. Creation of these hard points to protect diversions also impairs natural stream migration. In general, diversions situated within designated stream meander zones should be modular and designed to be removable to accommodate stream meander.

In general, the loss of river meander potential and functions in the Central Valley has resulted in more sterile river ecosystems upstream of the Delta, supports less habitat for anadromous and resident fish, and provides fewer nutrients and food to the Delta.

Issues and Opportunities

Channel Dynamics, Sediment Transport, and Riparian Vegetation: There is growing recognition that dynamic river channels, free to overflow onto floodplains and migrate within a meander zone, provide the best riverine habitats. The dynamic processes of flow, sediment transport, channel erosion and deposition, periodic inundation of floodplains, establishment of riparian vegetation after floods, and ecological succession create and maintain the natural channel and bank conditions favorable to salmon and other important species. These processes also provide important sources of food and submerged woody substrates to the channel. The most sustainable approach to restoring freshwater aquatic and riparian habitats is by restoring dynamic channel processes; however, restoration of natural channel processes is now hampered by the presence of levees and bank protection along many miles of rivers. Below reservoirs, the reductions in high flows, natural seasonal flow variability, and supply of sand and gravel have further exacerbated the constraining effect on rivers with levees and rock banks. It is therefore a priority to identify which parts of the system still have (or can have) adequate flows to inundate floodplains and sufficient energy to erode and deposit, and to identify floodplain and meander zone areas for acquisition or easements to permit natural flooding and channel migration. Sediment deficits from in-channel gravel mining should also be identified and the feasibility or efficacy of augmenting the supply of sand and gravel in reaches below dams should be evaluated.

Opportunities: Identify and conserve remaining unregulated rivers and streams and take actions to restore natural processes of sediment and large woody debris flux, overbank flooding, and unimpaired channel migration. Most rivers in the Central Valley are regulated by large reservoirs and therefore require considerable investment to recreate the natural processes needed to sustain true ecosystem restoration; however, a few large unregulated rivers still exist, such as the Cosumnes River and Cottonwood Creek. Lowland alluvial rivers and streams with relatively intact natural hydrology should be identified and made a high priority for acquisition of conservation and flooding easements, setting back of levees, and other restoration actions because such actions on these rivers are likely to yield high returns in restoration of natural processes and habitats and, ultimately, fish populations.

Undertake fluviogeomorphic-ecological studies of each river before making large investments in restoration projects. River ecosystem health depends not only on the flow of water, but on the flow of sediment, nutrients, and coarse woody debris and on interactions between channels and riparian vegetation, variability in flow regime, and dynamic channel changes. It is only through interdisciplinary, watershed, and historical scale studies that the constraints and opportunities particular to each river can be understood. For example, it was only after a fluviogeomorphic study of Deer Creek that the impact of flood control actions on aquatic and riparian habitat was recognized, a recognition that has lead to a proposal for an alternative flood management approach designed to permit natural river processes to restore habitats along Lower Deer Creek.

VISION

The vision for stream meander is to conserve and reestablish areas of active stream meander, where feasible, by implementing stream conservation programs, setting levees back, and reestablishing natural sediment supply to restore riverine and floodplain habitats for fish, wildlife, and plant communities.

INTEGRATION WITH OTHER RESTORATION PROGRAMS

Ecosystem Restoration Program Plan (ERPP) efforts may involve cooperation with other programs and organizations. These include:

- Upper Sacramento River Fisheries and Riparian Habitat Advisory Council (SB 1086) group efforts and river corridor management plans implemented for the Sacramento River (Resources Agency 1989);
- U.S. Army Corps of Engineers' proposed reevaluation of the Sacramento River Flood Control Project and ongoing Bank Protection Project, including more comprehensive floodplain management and river ecosystem restoration opportunities;
- Proposed riparian habitat restoration and floodplain management studies for the San Joaquin River, including potential new flood bypass systems and expanded river floodplains on lands recently acquired by the California Department of Parks and Recreation and U.S. Fish and Wildlife Service (USFWS);
- Anadromous Fish Restoration Program gravel replenishment programs and plans and small dam removal and/or fish ladder rehabilitation projects;
- The Nature Conservancy's ongoing Sacramento Valley conservation planning; expansion plans being made for the Sacramento River National Wildlife Refuge (USFWS) and California Department of Fish and Game's Sacramento River Wildlife Management Area;
- The Cosumnes River Preserve which is a joint project of The Nature Conservancy, Department of Interior, Department of Water Resources, Department of Fish and Game, Wildlife Conservation Board, and others.
- Plans for the San Joaquin River Parkway; plans being put into effect for all county-sponsored instream mining and reclamation ordinances and river and stream management plans; and reclamation planning assistance programs being initiated under the Surface Mining and Reclamation Act by the California Department of Conservation.
- The Riparian Habitat Joint Venture which promotes the coordinated development of riparian restoration plans with the primary purpose of conserving migrant land birds.

LINKAGE TO MULTI-SPECIES CONSERVATION STRATEGY

Stream meander is a dynamic ecological process that typifies a healthy river corridor or riverine ecosystem. A river-based ecosystem in the Central Valley extends laterally over its entire floodplain and longitudinally from its headwaters to the Delta or Bay. It may even extend beyond to hydrologically connected aquifers (California State Land Commission 1993). This view of stream meander as an essential component of a living river system is critical to the protection and restoration of aquatic, riparian, and terrestrial species addressed by the Multi-Species Conservation Strategy (2000).

LINKAGE WITH OTHER ECOSYSTEM ELEMENTS

Health stream meander corridors are dependent on the following ecological processes:

- Central Valley streamflows,
- Natural sediment supplies, and
- Natural floodplains and flood processes.

Habitat supported by healthy stream meander corridors are primarily related to riparian and riverine aquatic habitats, freshwater fish habitats, and essential fish habitats (for chinook salmon).

Many fish, wildlife, plant species, and plant communities are dependent on the riparian zone associated with stream meander corridors.

Stressors that impair the health of stream meander corridors include:

- Dams, reservoirs, weirs, and other human-made structures;
- Levees, bridges, and bank protection;
- Gravel mining;
- Invasive riparian plants; and
- Wildfires in the riparian zone.

OBJECTIVE, TARGETS, ACTIONS, AND MEASURES

The Strategic Objective is to increase the extent of freely meandering reaches and other pre-1850 river channel forms to support the restoration and maintenance of functional natural riverine, riparian, and floodplain habitats.

LONG-TERM OBJECTIVE: Reestablish active meander belts on all formerly meandering alluvial reaches in the Central Valley except those densely urbanized or with infrastructure whose relocation would have a high cost-to-benefit ratio.

SHORT-TERM OBJECTIVES: Inventory (at 1:1,200 scale or better) along all major river reaches bank conditions and land uses on adjacent floodplains. Prioritize for acquisition land or easements in rural areas with high potential for urbanization, especially around meander bends. Begin an acquisition program.

RATIONALE: Freely meandering rivers have the highest riparian and aquatic habitat diversity of all riverine systems. Through the process of meandering, eroding concave banks and building convex banks, the channel creates and maintains a diversity of surfaces that support a diversity of habitats, from pioneer riparian plants on newly deposited point bars to gallery riparian forest on high banks built of overbank silt deposits. Similarly, wandering or braided rivers support distinct habitat types and thus are beneficial to aquatic biota. Floodplain restoration can also increase flood protection for urban areas and increase the reliability of stored water supplies in reservoirs (because reservoirs can be maintained at higher levels because of reduced need to catch floodwaters).

STAGE 1 EXPECTATIONS: Plans for meander belts will have been developed for all major river corridors and priorities for land acquisition and easements established. Development of a meander belt will have begun on at least one river.

RESTORATION ACTIONS

The general targets and actions which will contribute to restoring healthy stream meander corridors include the following.

EXISTING RIVER MIGRATION ZONES

Appropriate reaches of the Sacramento and San Joaquin rivers and their major alluvial tributaries will be evaluated. Suitable portions will be designated as important river migration and floodplain deposition zones, or "meander belts." In these zones, natural erosion and sedimentation processes occur or could potentially occur unimpeded (within reasonable limits), sustaining a diversity of sediment-driven habitats.

These river reaches and potential meander zones will be eligible for river conservation programs and appropriate landowner incentives once they have been evaluated and ranked according to ecological process and function characteristics. Remaining Central Valley stream reaches where natural meander processes occur will be mapped and ranked according to the level of meander-system functions, the quality of dependent habitats, and the contribution to Delta species and important physical processes.

Stream Meander Corridors

Levees and floodplains along rivers of the Sacramento and San Joaquin valleys will be evaluated to determine if some levees can be set back to create new meander corridors or nodes of expanded floodplains and wider riparian forest. This approach also benefits flood safety and reduces flood protection maintenance costs by repositioning levees outside the primary bank migration pathway of alluvial streams, reducing the need for expensive rock riprap, and reducing the potential for levee breaches. Enlarging inadequate floodplains will increase the volume of safe floodflow, while allowing additional riparian vegetation within the channel to close gaps in the forest canopy. Riparian vegetation will tend naturally to recolonize stream meanders in areas where the channel is widened because point bar development and sediment capture will be enhanced. Vegetation removal practices, required in confined channels, are reduced with levee setbacks. The Sacramento River between Chico Landing and Colusa is an example of a partial levee setback that benefits both flood safety and habitat quality while reducing levee and channel maintenance costs.

In other areas, land use changes and land management costs in floodplains outside existing levees may no longer justify continual levee upkeep and future bank protection costs. These areas present additional potential for expanded river meander zones. Levees could be removed, breached in key locations, or allowed gradually to erode from river migration processes. An example is the floodplain of the lower San Joaquin River near Los Banos, where former livestock pasture has been acquired for wildlife management as part of the San Luis National Wildlife Refuge. Other examples are north Delta islands, where land subsidence and frequent levee failures have diminished the value of farmed lands.

Upstream and Bank Sediment Supply

The first step in restoring upstream and bank sediment supply is to identify and rank the sediment contribution of remaining non-dammed tributaries of alluvial rivers. These tributaries help support the dynamic equilibrium of meandering stream corridors and spawning gravel areas. River reaches where bank and floodplain gravels and sediment deposits are, or could reasonably be made, available to meandering rivers through natural erosion processes must also be identified. A variety of approaches will be needed to ensure that these remaining river sediment supply sources are conserved.

The potential ecosystem benefits of county mining ordinances which incorporate incentives and policies that promote replacing instream gravel mines with off-channel mines in high terrace deposits, abandoned dredger tailings, and reservoir delta deposits (deposits at the head of the impoundments) should be evaluated. The objective is to phase out instream gravel extraction that disrupts natural meander geomorphology and depletes annual sediment supply.

Dam Release Schedules During Wet Years

The potential for modifying reservoir storage management during wet years will be investigated. Releases during wet years could simulate the seasonal pattern of natural, short-duration flood peaks. The magnitude and duration of major natural flood peaks cannot be restored in rivers below large reservoirs, but even short duration high flows can contribute significantly to the physical forces that support meander formation. This was demonstrated by the experimental flows released on the Colorado River below Glen Canyon Dam, which redistributed channel sediments from tributaries to create new fish habitat and substrate for riparian vegetation. Dam releases can be combined with non-regulated tributary inflow below the reservoirs to create flow spikes of sufficient magnitude to mobilize bed and bank sediments, clean spawning gravels, and form new river corridor landforms.

MSCS Conservation Measures

The following conservation measures were included in the Multi-Species Conservation Strategy (2000) to provide additional detail to ERP actions that would help achieve species habitat or population goals. Although the measures were developed specifically for evaluated species, some measures have direct relationships to the manner in which stream meander influences habitat quality and quantity or have beneficial influences on evaluated species.

- Coordinate protection, enhancement, and restoration of channel meander belts and existing bank swallow colonies with other federal, state, and regional programs (e.g., the SB 1086 program, the Corp's Sacramento and San Joaquin Basin Comprehensive Study, the Anadromous Fish Restoration Program, and U.S. Fish and Wildlife Service recovery plans) that could affect management of current and historic habitat use areas to avoid potential conflicts among management objectives and identify opportunities for achieving multiple management objectives.

- Initial species recovery efforts should be directed to locations where there are immediate opportunities for protection, enhancement, or restoration of suitable habitat.

- Protect the Sacramento and San Joaquin river and tributary channels from physical disturbance (e.g., sand and gravel mining, diking, dredging, and levee or bank protection and maintenance) and flow disruptions (e.g., water diversion that result in entrainment and inchannel barriers or tidal gates) for the period February 1 to August 31.

- Implement management measures identified in the proposed recovery plan for the Sacramento River winter-run chinook salmon (National Marine Fisheries Service 1997).

- Implement applicable management measures identified in the restoration plan for the Anadromous Fish Restoration Program (U.S. Fish and Wildlife Service 1997) and the recovery plan for native fishes of the Sacramento-San Joaquin Delta (U.S. Fish and Wildlife Service 1996).

- Proposed ERP actions designed to protect or restore stream meander belts should initially be implemented along reaches of the Sacramento River and its tributaries that support nesting colonies of bank swallow or potential nesting habitat.

- Consistent with CALFED objectives, protect all known nesting bank swallow colonies from potential future changes in land use or activities that could adversely affect colonies.

- To the extent consistent with CALFED objectives, manage lands purchased or acquired under conservation easements to maintain or increase current population levels of resident evaluated species.

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◆ NATURAL FLOODPLAINS AND FLOOD PROCESSES

INTRODUCTION

Floodplains and flood processes provide important seasonal habitat for fish and wildlife, and provide sediment and nutrients to both the flooded lands and aquatic habitats of the rivers and Bay-Delta. Flooding also shapes the associated plant and animal communities. Major factors that reduce floodplain and flood processes contributions to the health of the Central Valley rivers and the Bay-Delta include construction of levees that constrict the floodplain, dams and reservoir operations that moderate flows, and activities that maintain flow capacity in major flood bypasses.

Before reclamation, Central Valley rivers and the Bay-Delta were comprised primarily of tidal and riverine floodplains in the form of vast tule islands, perennial grasslands, and riparian fringe corridors, intersected by permanent open water channels and secondary sloughs. Today only the primary open water channels remain, bordered by narrow, steep-sided floodplains sandwiched between the channel and the levee. Floodplains of the Bay-Delta provided a matrix for the interaction of secondary channel shorelines with tule marsh, riparian scrub, grasslands, and intertidal community types. Floodplains are essential to a balanced sediment budget by providing an area having lower velocity than the main channel, thereby capturing fine sediment and organic debris, and providing a more stable substrate for many vegetation types to flourish. During winter and spring flood events, floodplains provide important velocity refugia for resident and anadromous fish.

Floodplains reduce flood stages by slowing flow velocities, moderate channel incision and scour by providing a wide area for bank overflow, contribute to species diversity by creating the landforms that support different communities, contribute to the aquatic foodweb when overbank floodflows collect and transport organic matter from the floodplain back to channels and eventually the Bay-Delta estuary, provide low-velocity refuge for fish and other aquatic organisms during floods, and provide spawning habitat for fish species dependent on the Bay-Delta. Major factors that have disrupted floodplains and flood processes in the Delta and its tributaries include construction of levees that constrict the floodplain, dams and reservoir operations that moderate flow and block sediment, and activities that maintain flow capacity in major flood bypasses. Approaches to restoring more natural floodplains and flood processes include conserving existing natural floodplains and expanding confined floodplains.

RESOURCE DESCRIPTION

A natural floodplain is an important component of rivers and estuaries that allows many essential ecological functions to occur. Healthy floodplains are morphologically complex, including backwaters, wetlands, sloughs, and distributaries that carry ans store floodwater. Floodplain areas can constitute islands of biodiversity within semi-arid landscapes, especially during dry seasons and extended droughts. The term *floodplain* as used here means the generally flat area adjoining rivers and sloughs that is flooded by peak flows every 1.5-2 years and exceed the capacity of the channel ("bankfull discharge"). Peak flows in winter and spring that happen every 1.5-2 years are considered by river geomorphologists to be the "dominant discharge" that contributes the most to defining the shape and size of the channel and the distribution of sediment, bar, and bed materials. Larger flood events can cause major changes to occur, but they do not happen often enough to be the decisive factor in river geomorphology.

A more common use of the term *floodplain* refers to the 100-year floodplain as determined and mapped by the U.S. Army Corps of Engineers (Corps) and Federal Emergency Management Agency (FEMA). This definition is used to prepare land-use and flood-management plans.

Active floodplains provide many ecological benefits by:

- Slowing flow velocities
- Moderating channel incision and scour by providing area for bank overflow

- Contributing to species diversity by creating landforms that support different communities
- Contributing to the aquatic foodweb by collecting and transporting organic matter from the floodplain back to channels and eventually the Bay-Delta estuary
- Providing low-velocity refuge for fish and other aquatic organisms during floods
- Providing spawning habitat for fish species dependent on the Bay-Delta
- Providing habitats for wildlife such as shorebirds and dabbling ducks, and in high rainfall years, diving ducks.

One benefit of levees and flood control reservoirs is reducing the extent of and hazards within the 100-year floodplain and similar high-magnitude, low-probability storm events, as experienced in the January 1997 flood. The 100-year floodplain is related to a natural river floodplain but does not apply to the following discussion of ecosystem functions as supported by flood processes. A predicted 100-year floodplain covers a much larger area than a natural floodplain of a river, slough, or stream at bankfull discharge.

At higher flow, water spills out of the channel and flows over the flat-lying land near the river. River channels are not large enough to accommodate higher discharges without overflowing. This process of out-of-bank flow is a common but little recognized attribute of rivers and their floodplain.

Levees placed close to riverbanks have allowed human encroachment on river floodplains. Human encroachment on the floodplains of rivers accounts for the predominance of flood-related damage. Central Valley rivers that have little or no remaining natural floodplain, typically have the lowest ecological values and present the greatest risk of flood damage to adjacent lands. Large-scale reclamation and separation of low-lying land alongside rivers, streams, and estuaries have eliminated major habitat areas including riparian forests, marshes, and upper tidal zones.

On many tributaries, large reservoirs and diversions have also reduced the size of natural floodplains. Reservoirs and diversions reduce the frequency and duration of bankfull discharge and restrict channel flow to the low-flow channel most of the time, including during the wet season. In this case, a stream no longer comes into contact with its floodplain except during high-magnitude, low-frequency flood events. These types of streams may experience channel straightening and incision. The reduction of flood frequency on the lower floodplain often encourages encroachment of agricultural land uses and even recreational development on the area that once supported diverse floodplain habitats.

Floodplains reduce flood stages in the Delta, rivers, and streams by increasing the cross-sectional area of the channel and slowing flow velocities. Under overbank flow conditions, the river merges with its floodplain, increasing the capacity of the river to move and temporarily store large volumes of storm flow. Slow-moving water covering large riverine floodplains and adjacent basins naturally detains the volume of floodwaters entering the Delta and leveed reaches of the lower Sacramento and San Joaquin Rivers. Temporary floodplain storage thereby reduces the peak stage of flood events in the Delta region and other sectors of the levee system, and gradually releases the storm water as flood waters recede. The prolonged inundation of floodplains, such as can be observed in the Yolo and Sutter Bypasses and Stone Lakes basin, is highly compatible with the natural flood tolerance of seasonal wetland and riparian vegetation and animal life.

Floodplains capture and store sediment, build soil, and reduce the need for dredging channels downstream and in the Delta. The overbank flow across a floodplain is wider and more shallow than in the channel. The flow often encounters more resistance from vegetation along the outer banks, which causes the river to lose energy in the floodplain areas and, in turn, causes sand and fine sediment to be deposited. Natural levee mounds parallel the channel banks are created by the deposited sediment. The sediment also builds soil to support forests and grasslands. Natural floodplains are thus able to capture and store enormous volumes of fine sediment spread over large areas, balancing the river's sediment budget and preventing the clogging of channels and estuaries downstream.

Floodplain overflow moderates channel incision and bank scour. The term *stream power* refers to the ability of riverflow to erode the bed and bank by the shear stress created by deep, high-velocity, turbulent water. Rivers and streams confined to a narrow channel by bedrock canyon walls or constructed levees have greater stream power than alluvial rivers with unconfined adjoining floodplains. Energy and flood volume diverted into the overbank floodplain regulate the stream power acting on the channelbed and banks and, in concert with the binding effect of shoreline vegetation, prevent channel instability. Stream meander moderates the rate of change. Although many rivers and streams tend to experience some bed incision during high winter flows, the floodplain overflow capacity moderates stage increases and channel velocities that would otherwise cause excessive channel incision and widespread loss of riparian vegetation and riverine bed habitats during major storm events. Wide floodplains also reduce the scour effects on levees and bridge piers during high flows.

Floodplains contribute to habitat, and therefore, species diversity. During bankfull discharge, a flow/energy gradient exists from the channelbanks to the outermost extent of the natural floodplain. The flow/energy gradient results in a corresponding gradient from larger to smaller particle deposition and greater to lesser frequency of inundation. Scour effects are also greatest nearest the channel banks. The build-up of natural levee mounds and ridges may trap floodwaters in shallow, marshy basins formed between the outermost high ground and the sediment ridge deposited alongside the channel. These physical processes combine to create highly variable vegetation community types and age classes over the floodplain surface. The variation in plant species and community structure provides a wide array of habitat types and interfaces, resulting in the notably high wildlife species diversity found in riverine and estuarine corridors.

Floodplains are a major source of nutrients and organic matter for the aquatic zone. Floodwater passing over flat-lying lands captures organic material, carbon and nutrient-rich soil particles, insects, and fallen trees. These materials are transported at high flow stage to backwater basins, estuaries, and secondary channels that may then return the organic "cargo" to the river and Delta aquatic zone. These organic components provide microhabitats, prey items, and nutrients that sustain zooplankton, aquatic invertebrates, and small fish in the rivers and Delta.

Organic debris and dislodged trees may be captured by the filtering effect of the floodplain during one year, forming debris piles as floodwaters recede, and then be resuspended or swept away by a subsequent inundation of the floodplain. Without a floodplain to cycle buoyant matter conveyed by rivers and streams at high flow, most of the organic matter generated would be flushed through the system without being fully used. By detaining floodwaters longer than in the main channels, floodplains increase the residence time of nutrients, phytoplankton, and zooplankton, which promotes greater energy use and higher productivity of the foodweb entering the Delta.

Floodplains provide safe haven and spawning areas for native Delta and valley fish species. Fish, especially juveniles, seek lower velocity refuge from turbid, turbulent floodflows in rivers and streams. Vegetated floodplains adjoining channels provide ideal velocity refuge and overhead and instream cover during high-flow events. Here, small juvenile salmon, steelhead, and resident native fish can avoid excessive predation and weather the inhospitable stormflows in the main channel. Some fish species important to the Delta, such as splittail, will disperse from the rivers and sloughs into shallow, vegetated floodplains to spawn. Splittail recruitment is highest during wet years when the floodplains of the Delta and rivers, such as the lower Yolo basin, are flooded for a long time. In some areas, or under specific hydrologic events, poor drainage from floodplain and flood overflow areas can pose a hazard to aquatic organisms, primarily adult and juvenile fish, by contributing to stranding. Reconnecting rivers to their floodplains will be accomplished in ways sensitive to this risk and provide measures to reduce or eliminate it.

Floodplain function is affected by a number of common and widespread stressors, including levees and dams. Levees restrict the width and extent of floodplains in rivers and the Bay-Delta. In some areas, levees are only slightly wider than the channel at low flow, such as along the Sacramento River downstream of Colusa. Restricted floodplains typically cause deeper flow and faster channel velocity during high stage. They also restrict the amount and width of allowable or potential riparian vegetation, and have a low ratio of shallow-water habitats to deep, open water. Channels in these areas typically have a trapezoidal section, rather than a more natural compound channel with low bank angles and one or more flat-lying floodplain surfaces. Under these conditions, channels typically have a high depth-to-width ratio which is inherently unstable during high flows that can remobilize deep layers of channel bed materials. The physical processes necessary to sustain floodplain habitats may be absent or diminished. Within the Delta and Suisun and San Pablo Bays, levees restrict the extent of tidal floodplains inundated by higher high tides and storm flow surges passing through Delta sloughs and rivers.

Narrow floodplains along streams limit natural floodplain vegetation. Along rivers and streams contained within levee systems, the width of the floodplain is restricted, and much of the remaining floodplain surface has been reclaimed for orchard and cropland. Floodplain narrowing and conversion to cropland provides less inundation of vegetated areas during normal high water events, thereby reducing the input of critical nutrients and organic materials that typically come from a natural wide floodplain, and limiting rearing and spawning habitat for native fish such as splittail. In other cases, riparian vegetation is removed from the floodplain to optimize flood conveyance capacity if it is assumed that the predicted 100-year flood or "design flow"event will exceed the capacity of the channel.

Dams and reservoir operations reduce the natural peaks of a typical flood flow pattern, thereby reducing inundation of the natural floodplain. Large reservoirs on most of the Sacramento and San Joaquin Rivers tributaries capture the 1.5- to 2-year bankfull discharge. Water releases from reservoirs limit the magnitude, frequency, and duration of higher channel-forming flows that would otherwise spread into the lower floodplain areas adjoining rivers. Reservoirs also capture most of the incoming fine sediment that is needed to build soil on the floodplain. The net effect is to convert rivers and streams below dams into much smaller versions of the original channel and floodplain.

Managed reservoir releases may not be sufficient to interact with the remaining patches of floodplain except during higher magnitude stormflows. This is especially true on rivers such as the American River, where there are no major nondammed tributaries downstream of Folsom and Nimbus Dams. Channel incision that often follows dam construction and associated loss of the natural sediment supply further exacerbates the shrinkage of the floodplain alongside the lowered channel.

Flood management programs and policies affecting the Sutter and Yolo Bypasses discourage vegetation in the floodplain. Although the Yolo and Sutter Bypasses provide some of the physical functions of natural flooding and floodplain benefits, the full ecological potential of the floodplain is not realized because of the artificially uniform grade and generally sterile, nonvegetated condition of most of the bypass system. As recently as 1960, there were still hundreds of acres of natural grassland and valley oak woodland in the bypass system, most of which have been removed to improve floodway conveyance and make way for more intensive cropping patterns.

ISSUES AND OPPORTUNITIES

FLOOD MANAGEMENT AS ECOSYSTEM TOOL: The current approach is to control floods using dams, levees, bypass channels, and channel clearing. This approach is maintenance intensive, and the underlying cause of much of the habitat decline in the Bay-Delta system since 1850. Not only has flood control directly affected ecological resources, but confining flows between closely spaced levees also concentrates flow and increases flood problems downstream. Without continued maintenance or improvement of flood control infrastructure, further levee failures are likely. Emergency flood repairs are stressful to local communities and resources and often result in degraded habitat conditions. An alternative approach is to manage floods, recognizing that they will occur, they cannot be controlled entirely, and have many ecological benefits. Allowing rivers access to more of their floodplains actually reduces the danger of levee failure because it provides more flood storage and relieves pressure on remaining levees. Valley-wide solutions for comprehensive flood management are essential to ensure public safety and to restore natural, ecological functioning of river channels and floodplains. Integrating ecosystem restoration with the Army Corps of Engineers' Comprehensive Study of Central Valley flood management can help redesign flood control infrastructure to accommodate more capacity for habitat while reducing the risks of flood damage (Strategic Plan 2000).

BYPASSES AS HABITAT: The Yolo and Sutter Bypasses along the Sacramento River are remarkably